Design and Testing of the Millisecond Shutter at the Dynamic Compression Beamline (DCS) at the Advanced Photon Source (APS)

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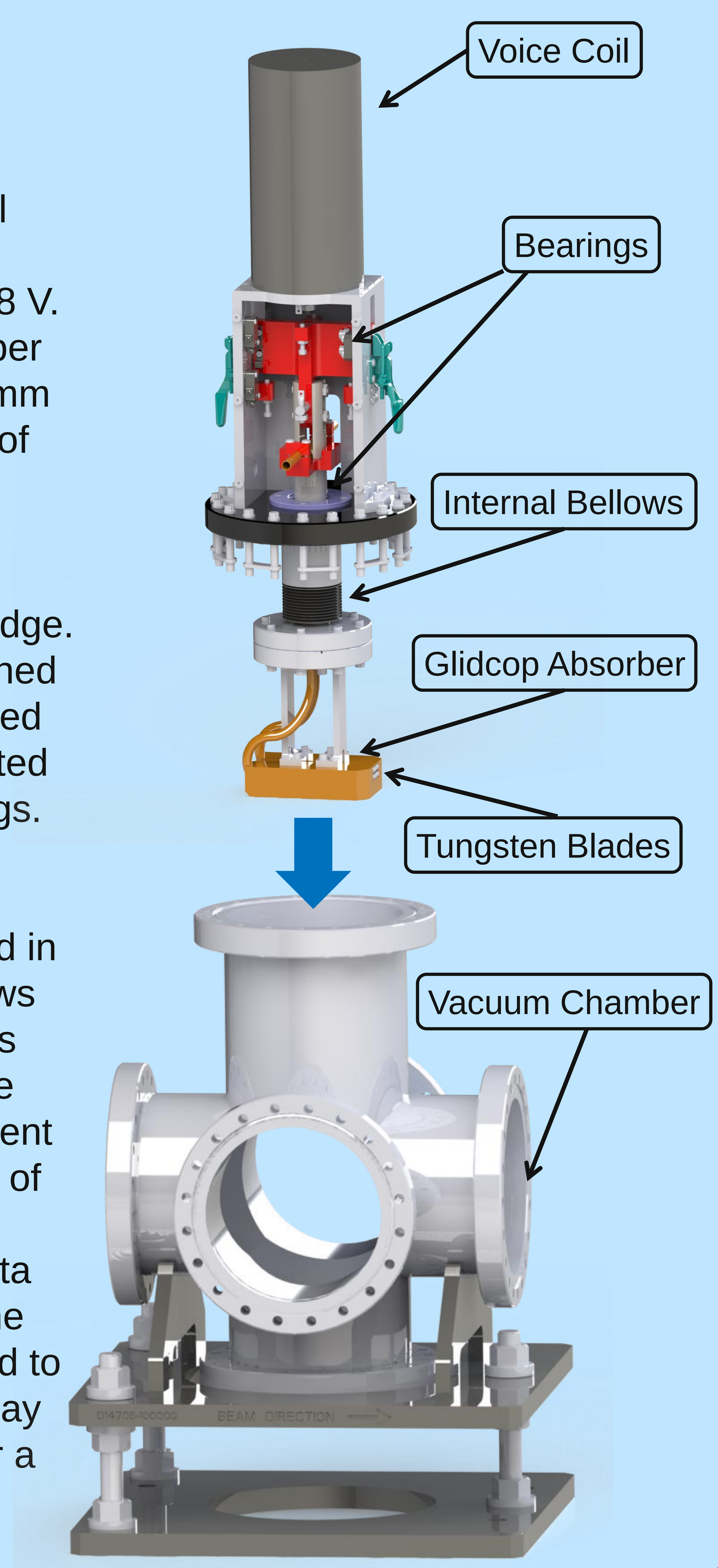
Introduction

“The National Nuclear Security Administration (NNSA) of the Department of Energy (DOE) is sponsoring the development of the Dynamic Compression Sector (DCS), a first-of-a-kind user facility dedicated to dynamic compression science. Washington State University (WSU) is leading the effort to develop and build the DCS infrastructure and instrumentation (at Sector 35 on the APS experimental hall floor), in collaboration with the APS; DOE/NNSA National Laboratories (Los Alamos, Lawrence Livermore, and Sandia); Department of Defense Laboratories, including the Army Research Laboratory and Naval Research Laboratory; and academic institutions. The DCS represents an exciting and visionary capability in support of the NNSA’s scientific mission, and offers an opportunity to pursue fundamental science that has not been possible at any synchrotron radiation facility to date.”[1]

The DCS beamline will enable users to conduct in-situ, time resolved studies of samples subject to extreme dynamic compression by means of a gas, or powder gun. In order to illuminate the sample without destroying it, DCS requires a device that is able to deliver a quick pulse of beam to the sample, synchronized with the gun shot. The Millisecond Shutter has been designed and tested, and is currently in use at the DCS beamline.

Design

The Millisecond Shutter uses a BEI KIMCO electrodynamic actuator to translate an in-vacuum Glidcop absorber. The high-power voice coil has a peak force of 1512 N and a maximum current draw of 20 A at 78 V. The water cooled, V-shaped absorber is designed to handle the 3mm x 1mm beam at a grazing incidence angle of 4˚. Tungsten blades on the downstream end of the absorber prevent transmission through the copper and ensure a sharp beam edge. The motion of absorber is constrained along the vertical axis using a flanged ball bearing, and rotation is eliminated using a pair of standard ball bearings. The mass of the moving parts is minimized to increase acceleration, and a small, internal bellows is used in order to minimize jitter due to bellows vibration. A pair of extension springs counteract the vacuum force on the bellows which eliminates static current draw by the voice coil. The position of the absorber is read by a linear magnetic encoder and fed to a Delta Tau, closed loop control system. The PID control loop has been optimized to shorten pulse length. The design may also be used as a beam chopper or a precise, movable mask.



Analysis

A dynamic model of the system was first created in MATLAB Simulink and controlle8d via an optimized PID module. The transfer function for the electromechanical system consisting of a mass, spring, and electromagnet is given below:

$$\frac{X(s)}{V(s)} = \frac{K_f}{mLs^3 + (mR)s^2 + (kL + K_f K_e)s + kR}$$

X = Displacement
V = Voltage
K = Spring Constant
R = Resistance
M = Mass
L = Inductance
K_f = Force constant
K_e = Velocity constant

Figure 1 shows a graph of position vs. time for a step input, using the optimized PID controller. Given the vertical size of the aperture and beam, the total minimum open time for the shutter is calculated to be **2.9 mS**.

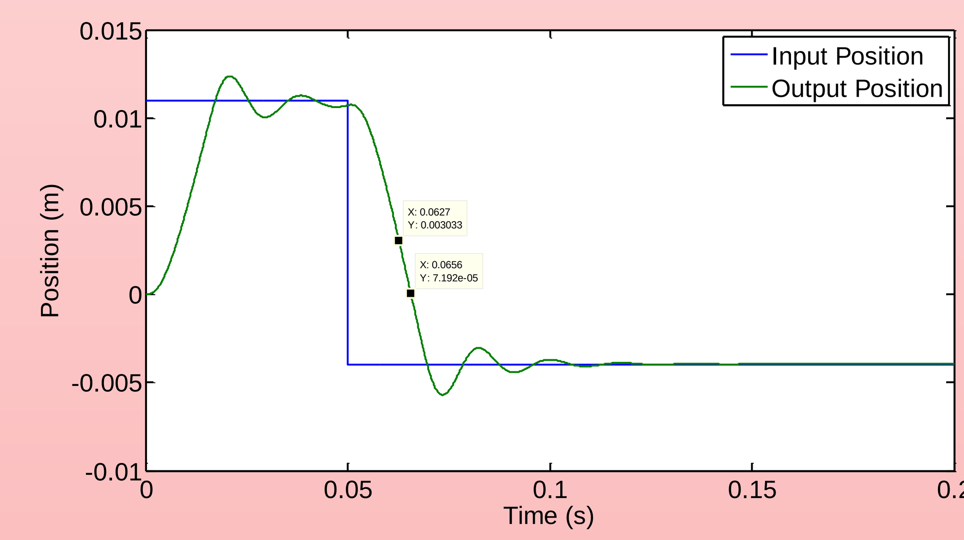


Figure 1. Calculated response to step input

An ANSYS model of the absorber (Figure 2) was created to determine thermal performance. The absorber can handle a maximum of 1939W (continuous) with a maximum temperature of 349˚C until boiling the cooling water.

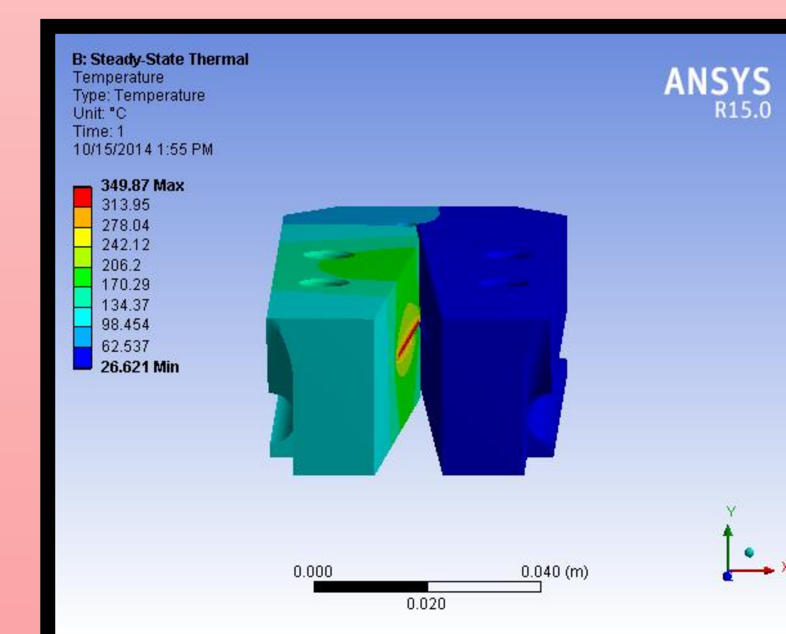


Figure 2. Temperature distribution

Testing

After installation, the Millisecond Shutter was tested and characterized using the APS beam. Figure 3 shows a plot of open time vs. velocity set point, which is given in units of encoder counts per mS, and it is entered via a custom EPICS interface. Figure 4 shows a plot of the pulse profile. The minimum open time, FWHM, was measured to be **3.9 mS**. The standard deviation of the insertion delay, or “jitter”, was measured to be 100 µS. A picture of the Millisecond Shutter installed in S35 is shown in Figure 5.

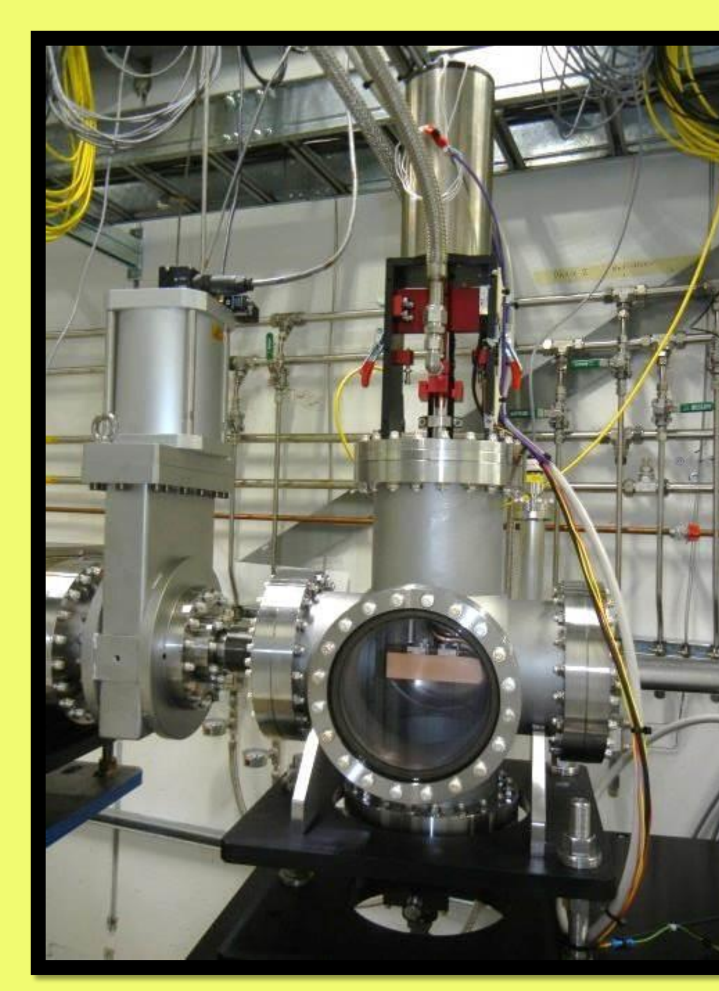


Figure 5. Millisecond Shutter installed in S35

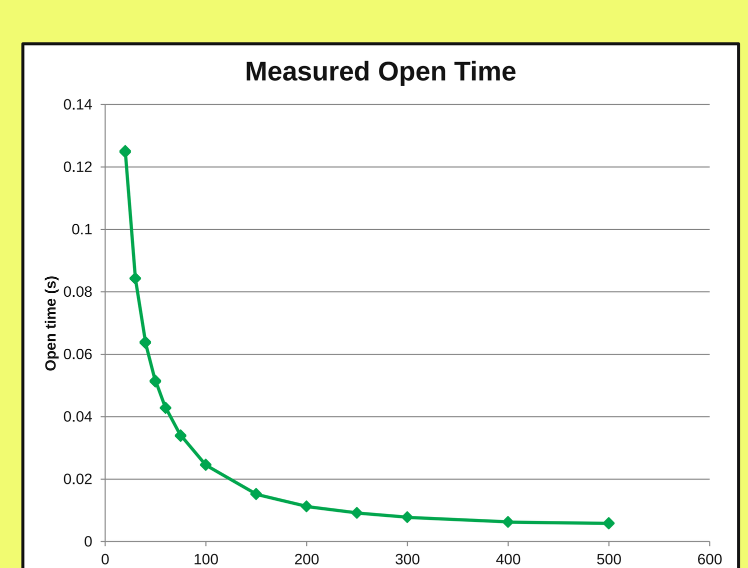


Figure 3. Open time vs. velocity set point

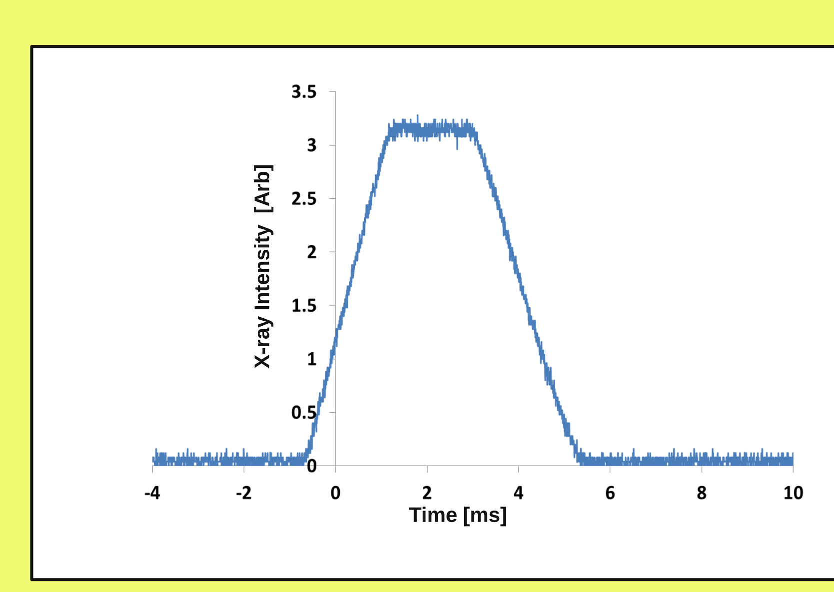


Figure 4. Shutter pulse profile

References

1. "Dynamic Compression Sector | WSU." *Dynamic Compression Sector | WSU*. N.p., n.d. Web. 16 Oct. 2014. <http://www.dcs-aps.wsu.edu/>.